NAVAL POSTGRADUATE SCHOOL
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THESIS

A CASE STUDY OF THE APPLICATION OF RELIABILITY CENTERED MAINTENANCE (RCM) IN THE ACQUISITION OF THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV)

by

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December 2002

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This thesis examined the application of Reliability Centered Maintenance (RCM) in the acquisition of the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV). RCM is referred to throughout various service and DoD wide references, but in the absence of specific guidance on how to apply RCM to an acquisition, the AAAV program provided a unique opportunity to analyze key decisions and results. The research included an examination of the RCM process to include RCM training provided on site at the AAAV program, a review of pertinent program documents, interviews with program representatives, and an analysis of the critical decision to utilize the RCM process. The key findings of the research effort concluded that when RCM is applied to an acquisition with program commitment, the program will gain a greater, more focused understanding of the system and subsystems, than with the traditional Failure Modes and Effects Analysis (FMEA) and Failure Modes, Effects and Criticality Analysis (FMECA). AAAV also demonstrated that RCM benefits were broad and not limited to just maintenance analysis and that these benefits could be gained at any stage of the acquisition. This thesis concludes by recommending that the acquisition community recognize the benefits and institutionalize RCM into the acquisition process.

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A CASE STUDY OF THE APPLICATION OF RELIABILITY CENTERED MAINTENANCE (RCM) IN THE ACQUISITION OF THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV)

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) has been under close scrutiny by Congress over the past two decades because of its inability to field major defense acquisitions on time and within budget [Ref. 1:p. 21]. Previous attempts by DoD to reform its acquisition process have met with limited success. The attempt initiated in 1994 strives to reform the procurement process by examining every step in the process and determining if there is a better way to do business. Some of the central themes to the acquisition reform initiative include adopting commercial business practices, use of Integrated Product and process Development (IPPD) and Integrated Product Teams (IPTs), Cost As an Independent Variable (CAIV), and use of Performance Specifications vice Military Design Specifications. [Ref. 2]

In 1996, the Logistics Strategic Plan prepared by the Deputy Under Secretary of Defense (USD) for Logistics and promulgated by the Deputy USD for Acquisition and Technology stated that the DoD Logistics System would meet the vision of providing reliable, flexible, cost effective and prompt logistics support, information and service to the warfighter. The DoD is to meet this vision proactively by making investments into technology, training, process reengineering, and employing the successful commercial and governmental practices. [Ref. 3:p. 10] The Department's latest vision for acquisition was published in DoDD 5000.1 and DoD Instruction 5000.2, effective October 23, 2000.

[Ref. 4] These regulations further direct decision-makers to take all appropriate enabling actions to integrate acquisition and logistics to ensure a superior product support process. [Ref. 5]

Program Managers (PM) for major defense acquisition programs are ultimately responsible for logistics management activities throughout the system development process, in order to ensure the design and acquisition of cost effective, supportable systems. This includes the long-term goal of providing the warfighter with the necessary support infrastructure to achieve readiness requirements. [Ref. 3:p. 28.] PMs have many tools available to assist them in managing their programs but there is no substitution for experience. PMs must also draw upon the experiences of others to avoid repeating mistakes. Lessons learned from successful programs are published so that everyone within the acquisition community can see which initiatives were successful and which ones were not. This case examines the lessons learned in the application of Reliability Centered Maintenance (RCM) in the acquisition of the Marine Corps' Advanced Amphibious Assault Vehicle (AAAV) program.

B. RESEARCH OBJECTIVE

The objective of this research is to examine the program decision to utilize RCM in the Marine Corps AAAV program. The goal is to determine what impact this decision has had on the AAAV program, the future implications of this decision and to determine if this decision can benefit other defense acquisition programs. The research includes conducting a thorough review of the

RCM process to include actual RCM training provided on site at the AAAV program, a review of pertinent program documents, conducting interviews with program representatives, and conducting an analysis of the critical decision to utilize the RCM process.

C. RESEARCH QUESTIONS

The primary research question is: What have been the results of applying the RCM process in the acquisition of the Marine Corps AAAV and what are the reliability expectations associated with the further development, production and deployment of the AAAV? The subsidiary research questions are as follows:

- What is Reliability Centered Maintenance (RCM)?
- What are the current acquisition guidelines for reliability?
- How has the AAAV program utilized RCM?
- How might an analysis of the AAAV PMO decision to utilize the RCM be used in the successful execution of other DoD acquisition programs?

D. SCOPE

The scope of this case is limited to determining what RCM lessons can be learned from the AAAV. The study will analyze both the RCM process and the application of RCM made within the PMO.

E. METHODOLOGY

The methodology used in this research consisted of the following: (1) a literature search of books, articles and other documents relating to RCM, the federal acquisition process and the AAAV program, (2) a review of available AAAV program related material, and (3) personal, telephonic, and e-mail interviews with personnel assigned

to the AAAV PMO, Marine Corps Systems Command, and General Dynamics (the prime contractor for the AAAV).

F. ORGANIZATION OF THE STUDY

This thesis is organized in the following manner: Chapter I presents the background and research questions for the study. Chapter II examines the generic RCM process and DoD policy on RCM. Chapter III examines the application of RCM to the acquisition of the AAAV. Chapter IV analyzes the advantages and disadvantages of RCM in the AAAV program. Finally, Chapter V contains the conclusions drawn from the research and recommendations for actions that can be taken.

II RELIABILITY CENTERED MAINTENANCE

A. INTRODUCTION

This chapter will examine the generic RCM process, which provides one source of innovation in maintenance management that has proven its value in both commercial and military applications. RCM has helped develop management policies and improve reliability in a wide variety of applications through a methodical approach that ensures an organization's maintenance management plan is efficient in addressing high operational tempos, fiscal constraints, personnel shortages, scarcity of resources, aging equipment, safety awareness, and environmental integrity. RCM has the potential to ensure reliability is accounted for in our military assets, but there is little reference to the process in official DoD wide regulations.

B. RCM DEFINED

RCM is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context. [Ref. 6] This is a simple statement, but contains crucial changes in the way maintenance is defined. The RCM process refocuses thinking in four significant ways:

1. The objective of a successful preventive maintenance program should be to prevent or mitigate the consequences of failures, not to prevent the failures themselves. Failures cannot be prevented. For example, if a wheel bearing on a car starts making noise (an indication that it is failing), it's likely that it will be replaced. This does not prevent the failure of the bearing but instead, avoids the consequences of the eventual failure. Of the numerous

possible failure modes on any piece of equipment or system, each has a potentially different effect on safety, operations, the environment or costs. It is this effect or consequence that should determine what, if any, attention should be used to address these occurrences. This leads to the ultimate maintenance management conclusion that if the consequence of a failure does not adversely affect safety, operations, the environment or costs, then there is no need to perform any scheduled preventive maintenance at all.

2. The consequences of a failure will differ depending on the operating context of the asset. For example, an automobile that a farmer uses to run between his house and his barn (1 mile away) will probably not be subjected too much scheduled car care since its failure has minor consequences (a short walk to the barn). However, if this same car was going to be used to travel across the country, the prudent owner will likely invest the money and time to ensure that all recommended maintenance be performed and that the vehicle is roadworthy prior to such a trip. The consequences of failure in this context (possibly 2,000 miles away from home) are far more significant than those in the context of the farmer’s car. A formal review of failure consequences focuses attention on maintenance efforts that avoid serious consequences and diverts energy away from those with little or no effect.

3. There is a growing realization that in some cases, scheduled preventive maintenance (PM) can actually be detrimental. Performing certain tasks causes an otherwise stable system to be destabilized and can lead to maintenance-induced failures. Consider the case of a ball or roller bearing supporting a drive shaft. An ill-advised PM service may call for the replacement of the bearing at some interval (say 2 years). Since almost all bearings follow a completely random failure pattern, the time-based replacement of this bearing in the absence of any failure indicators provides an opportunity to incorrectly

install the “new” bearing and arguably throws away a perfectly good “old” bearing. Although actuarial data is virtually non-existent, it’s interesting to note observations of Marine Corps ground equipment over the past 25 years. In garrison, heavy emphasis is given to ensuring that all scheduled PM is accomplished precisely as specified in the applicable technical manual. In the field and particularly during extended operations however, “scheduled” PM all but falls by the wayside and at the same time, equipment availability and reliability seem to noticeably increase. The theory is that in garrison, there is more opportunity to induce failure by performing scheduled services. More often than not, the traditional PM that has not been validated by the RCM process will lack the focus of doing the job right. [Ref. 13]

4. The final paradigm change is that instead of being concerned about what we want a process or piece of equipment to “be,” we should focus on what we want it to “do.” In order to achieve this focus, the functions (or requirements) for the item must be clearly and precisely understood. It is only when the functions (what the item must “do”) are fully defined that functional failures and the specific failure modes that cause them can be identified. And it is only when failure modes and their effects are understood that an effective management policy can be established to avoid the consequences of each failure mode.

RCM builds on these simple ideas to determine applicable and effective maintenance management plans for each failure. [Ref. 7]

C. RCM BACKGROUND

RCM was developed over a period of thirty years, but was first defined in 1978 by Stan Nowlan and Howard Heap in a report titled *Reliability-Centered Maintenance* commissioned by the U.S. Department of Defense (DoD).

Since then, and most notably within the last decade, RCM has attracted considerable attention, both from potential users and from consulting firms' eager to turn those users into clients. One result has been a confusing abundance of processes offered by consultants under the name "RCM." Consequently, numerous organizations have attempted to bring order to this situation by publishing standards for RCM. [Ref. 8]

The first industry to attempt a detailed examination of the effects of equipment failure was the aviation industry. The Air Transport Association challenged many of the widely held beliefs on maintenance and developed a new framework to guide the development of scheduled maintenance programs for new airliners with the goal of ensuring that all assets continue to perform, as its users want them to perform. Although as the Maintenance Steering Group 1 (MSG1) and MSG2 (predecessors to MSG3) documents revolutionized the procedures for developing maintenance programs for aircraft, their application to other types of equipment was limited by their brevity and specialized focus. [Ref. 6]

The Nowlan and Heap report revealed the success that commercial aviation had enjoyed with their revolutionary approach to scheduled maintenance and DoD hoped to benefit from this new process. In the mid-1980s, the services published Military Standards and Specifications to guide contractors in using RCM to develop maintenance programs for new military equipment. In June of 1995, the U.S. Secretary of Defense established a new policy, DoD Instruction 4151.18, to rely on commercial standards

instead of the traditional military standards for major acquisition programs. Unfortunately for the Defense logistics community, there was no commercial standard outside of civil aviation that fully described RCM.

In October 1999, the Society of Automotive Engineers (SAE) published the first all-industry commercial standard for RCM. SAE JA1011, *Evaluation Criteria for RCM Processes*, established the minimum criteria a process must include to be called an "RCM" process. [Ref. 9] The SAE committee chair, Dana Netherton, ensured the standard did not attempt to define a specific RCM process, but rather provided a basis for those interested in ascertaining whether companies were indeed providing true RCM services. This is a key point because there are many organizations that claim to provide RCM services but have taken the liberty to remove key portions in an attempt to shortcut the process to make a quicker profit. Some of these processes may have achieved the same goals, but a few were counterproductive and some were even dangerous. [Ref. 10]

The military aviation communities were the first DoD participants to take advantage of the RCM process, since the original studies were tailored towards commercial aviation. RCM within commercial aviation has evolved over the years and the commercial aviation industry and the Federal Aviation Administration (FAA) know the current version of RCM as MSG3. Ironically, the RCM process seems to have been ignored for most existing ground mobility equipment (i.e., truck, tanks, tractors etc.) As a result, industries seeking minimum effort, inexpensive, quick fix solutions have been disappointed. Consequently, RCM has

received mixed reviews in its application in general industry. [Ref. 11]

D. RCM FUNDAMENTALS

As previously mentioned, the Society of Automotive Engineers published the all-industry commercial standard for RCM. SAE JA1011 states that in order to be called a RCM process; it must obtain satisfactory answers to these seven questions, which must be asked in this order:

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?

2. In what ways can it fail to fulfill its functions (functional failures)?

3. What causes each functional failure (failure modes)?

4. What happens when each failure occurs (failure effects)?

5. In what way does each failure matter (failure consequences)?

6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?

7. What should be done if a suitable proactive task cannot be found (default actions)? [Ref. 9]

What are the functions and associated performance standards of the asset in its present operating condition? Before it is even possible to apply a process used to determine what must be done to ensure that any physical asset continues to do whatever its users want it to do in its present operating context, we need to do two things:

determine what it’s users want it to do and ensure that it is capable of doing what it’s users want to start with. [Ref. 6] This is precisely why the first step in the process is to define the functions in the proper context with the desired expectations. This user expectation can be broken down into primary and secondary functions. Primary functions would include factors such as speed, output, capacity, quality, or customer service. Secondary functions might include safety, control, comfort, efficiency, environmental compliance and appearance. Users know these functions better than anyone else does, so it is essential that they be included in the RCM process from the beginning.

Until a group becomes thoroughly versed in the RCM process, defining functions can take up to one-third of the total time involved in an analysis. This is because for many, RCM is the first process that forces them to describe in accurate detail, what they want something to do instead of generically describing what they want it to be. This part of the RCM process has an added benefit in that; it brings the team together as they learn as group how the equipment actually works.

In what ways does the equipment or system fail to fulfill its functions? At what point is the loss of performance unacceptable? These questions force an RCM group to clearly describe at what point they consider that the equipment has “failed.” RCM defines this condition as a “functional failure,” because when one occurs, an asset cannot perform its function to the user’s standard.

What causes each functional failure? Once functional failures have been identified, the next step is to try to identify all of the events (failure modes) that are reasonably likely to cause the failed state. Likely failures include those that have occurred on the same or similar equipment while operating in the same context, failures that are currently being prevented by some existing practice (i.e., preventive maintenance) and failures that have not happened but are real possibilities. RCM also considers failure modes that are thought to be unlikely, but if they should occur, would have extremely serious consequences, such as death or a catastrophic environmental breach. Most failures are caused by deterioration, normal wear and tear, human error, and design flaws. The key is to be able to identify each failure in enough detail to be able to put together an appropriate failure management policy. Verbs such as ‘fails’ or ‘breaks’ or ‘malfunctions’ are too generic in most cases to develop an effective management solution; therefore, RCM suggests that review groups describe failure modes with much greater precision. This is of extreme importance because in many instances, the effects of a failure are confused with the mode of the failure.

As a result, many maintenance policies have been created that manage failure effects instead of failure modes. For example, consider the case of a geared hydraulic pump driven by a shaft. Consider now one possible failure of the shaft: “shaft shears.” If the shaft is built to minimum standards with little or no safety margin, it is possible that the shaft could shear due to fatigue. In this case, the failure mode should read

“shaft shears due to fatigue” and it’s possible that a management policy (i.e., design a stronger shaft, inspect shaft every XXX hours and replace if worn, reduce load on pump, etc.) based on the operating context of the pump can be developed. However, if the shaft is built to greater, robust standards, the shaft shearing is much more likely to be an effect of some other failure mode (i.e., pump seized, motor over speed, improper installation) and any management policy directed at the shaft would be unlikely to avoid the consequences of the pump failing.

What happens when each failure occurs? It is important to describe the effects of each failure mode and in doing so, describe them fully and as if nothing is being done to predict or prevent the failure. In describing the effects, the following questions should be addressed: What evidence is there that a failure has occurred? In what ways does the failure pose a threat to the environment or to safety? How does it affect operations or production? What physical damage is caused by the failure? What must be done to repair the failure? If the effects are not complete, it is possible that the consequences of the failure will be understated and that an improper and possibly deadly management policy will ensue.

In what way does each failure matter? This question established the consequences of each failure mode and is at the heart of establishing a management policy. Since not every possible failure mode can realistically be addressed with the same vigor, the ones that have serious consequences will be the ones that we will go to great lengths to avoid. One of the strengths of RCM is the

recognition that the consequences of failures are more important that their technical characteristics. The real reason for doing proactive maintenance is not to avoid failures, but to avoid or reduce the consequences of failure.

The RCM process classifies consequences into one of five distinct categories: hidden failures, safety, environmental, operational, and non-operational with hidden being viewed as most important and non-operational as the least. As a general rule, hidden failures describe the failure of protective devices that in and of themselves have no direct consequence. However, when coupled with another failure (a “multiple failure” in RCM terms), the consequences can be severe. RCM gives these top priorities because in many instances, the existence of the protective devices is unknown to the user of the asset. As an example of a hidden failure, consider a low oil pressure shut-off switch on an engine. If the engine oil pressure is within normal limits and the switch is failed, it does not matter. The only time the failed switch matters is when oil pressure drops; the multiple failure. A failure has safety consequences if it could injure or kill someone and has environmental consequences if it violates corporate or governmental environmental standards. A failure has operational consequences if it affects output, quality, service or operating cost and finally, if none of the former apply, the consequences of the failure is said to be “non-operational.”

RCM uses the above categories as the framework for decision-making. This helps to shift emphasis away from

the thought that all failures “matter” and must be prevented. By focusing maintenance resources on those failure modes that matter, energy and resources are not wasted on those that have little or no effect. This also forces managers to look for innovative ways to manage failure rather than concentrating only on failure prevention. Failure management can be divided into two categories, proactive tasks or default actions. Proactive tasks such as preventive maintenance or scheduled restoration are performed before the failure happens. Default actions are considered when a proactive task is not possible and includes failure finding, redesign, or run to failure.

What can be done to predict or prevent each failure? Historically, the belief was that the best way to optimize equipment availability was some type of proactive maintenance on a scheduled basis. The assumption was that most equipment operates reliably for a period of time and then wears out; the assumption that everything has a “life.” Recent studies, however, have revealed that equipment does not always behave as we thought it once did and that not everything has a life that can be used to develop maintenance policies. As the understanding of how equipment behaves has increased, so has the realization that in some cases, the more often equipment is overhauled, the more likely it is to fail. This is referred to as introducing infant mortality into an otherwise stable system. [Ref. 12] With this in mind, some organizations have chosen to arbitrarily abandon all forms of preventive maintenance, but this can lead to significant failure consequences. The RCM solution is to examine each failure

mode on its own and through a disciplined process, establish whether or not a proactive task is applicable.

RCM suggests one of three possibilities for proactive tasks and addresses them in the order of easiest/least expensive to most expensive. The first consideration is for an ”on-condition” task. An on-condition task is a scheduled check to see if something is giving an indication or warning that it is failing: a noisy bearing, for example. If it is indicating imminent failure, corrective maintenance is performed. If it is not, nothing is done until the next check. In other words, maintenance actions are based on the condition of the asset. The second consideration is scheduled restoration and the third is scheduled discard. In these cases, an item is either restored or discarded at a prescribed interval regardless of the condition of the “old” item at the time. Only components that have an “expected life” will fall into a scheduled restoration or discard regime and RCM establishes clear guidelines to decide which is the most appropriate based on the failure mode under review. With that said, between 75-89% components do not have a life and thus, proactive tasks are not technically feasible and scheduled maintenance can be argued as counterproductive. [Ref. 13]

What if a suitable proactive task cannot be found? If a proactive task cannot be found then a default action must be considered. Default actions include failure finding, re-design and no scheduled maintenance and are based on the consequences of the failure mode. For example, in the case of hidden failures, if a proactive task cannot be found, or if a suggested task does not reduce the risk of multiple

failures to a tolerable level, then a scheduled failure finding task may be prescribed. Failure finding involves checking to ensure that the device is still working. In the case of the low oil pressure switch described earlier, a failure finding task might involve removing the switch and checking its operation on a test bench to ensure that it sent the proper signal when oil pressure was reduced to a prescribed level. If a suitable failure finding task cannot be found, and the consequences of failure include either safety or the environment, redesign is compulsory. If the consequences do not affect safety or the environment, no scheduled maintenance is prescribed and redesign may be desirable. RCM suggests that if a suitable proactive task cannot be found for any failure mode with safety and environmental consequences, then redesign is compulsory to prevent or reduce the consequences of the failure. Nowadays, companies cannot afford safety and environmental mishaps since they come with large monetary penalties as well as damaged reputations. If the failure has either operational or non-operational consequences then any proposed task must be economically justified. If an economical task cannot be found, no scheduled maintenance is the default with redesign as an option.

The approach discussed in the previous paragraphs calls for proactive tasks only when they are suitable for the specified failures mode. This can clearly lead to a substantial decrease in routine scheduled workloads. It is logical to reason that the fewer the number of scheduled tasks, the more likely it is that the tasks will all be properly completed. This approach, plus the elimination of potentially counterproductive tasks, leads to a more

efficient and responsive maintenance program. This is an important issue to appreciate. When you think about it, in the traditional approach to developing maintenance procedures, the requirements for each asset were assessed in terms of technical characteristics without consideration to the consequences of failure. These maintenance schedules would then be used as blanket policies for all other similar assets regardless of the different operating contexts and as a result, they led to unnecessary maintenance with a potential to induce more failures than they prevented. These large numbers of schedules are really both a waste of time and resources, since they often achieve far less than was expected, and are sometimes counterproductive. [Ref. 6]

E. APPLYING RCM

There are many references published describing the RCM process and organizations with limited funds to invest might be tempted to simply read the references and attempt to apply the process to “save money.” Though the RCM process is seemingly straightforward and simple to comprehend, it should not be applied by anyone who has not been properly trained and mentored. RCM is as much a scientific discipline as mechanical engineering or medicine. Simply reading about RCM in a book, attending a short class on the subject, listening to a speaker describe the process at a symposium or observing the process being applied does not ensure that it can be successfully and effectively applied without proper follow-on training and mentoring. If it were that simple, then anyone could pick up a copy of “Gray’s Anatomy,” read it from cover to cover, and be instantly qualified to diagnose ailments, prescribe

treatment and possibly perform surgery with no other training. [Ref. 13]

If RCM is correctly applied, results are quick to follow, however, success is more likely to come to those who thoroughly plan as well as carefully consider how and by whom the analysis is performed, audited and implemented. Meticulous preparation begins with defining the scope, boundaries and objectives of each project, and identifying a project manager, facilitators and participants by name. Additional planning includes determining the training for participants and facilitators, the details for each meeting, management audits of RCM recommendations, and deciding how to implement these recommendations.

RCM should be first applied to systems where it is likely to get the biggest return relative to the effort required to achieve either tangible or intangible benefits. Tangible benefits include greater safety, improved equipment availability and reliability, better product quality and customer service, and lower operating or maintenance costs. Intangible benefits include a better understanding of how the equipment works from the operator and maintainer point of view, improving teamwork, and increasing morale. Hopefully these systems are self-evident, but it may be necessary to prioritize the RCM projects before planning each project in detail.

To prioritize and keep the process focused, RCM utilizes small teams of key personnel called review groups. These teams are necessary since a single person generally cannot effectively answer every one of the original seven questions discussed earlier. The ideal group consists of

an engineering supervisor, craftsman, operations supervisor, operator, external technical or process specialist, and is led by a trained facilitator. Each should have a thorough knowledge of the equipment under review and an understanding of the RCM process. The idea is that management gains access to the knowledge and expertise of each team member, while the members themselves gain a greater appreciation for how the asset works. This teamwork plays an integral part in the overall success of the process.

The facilitators are the experts in RCM and thus ensure the entire process is understood and applied by the group. Along the way, the facilitator ensures consensus is reached, commitment is retained, the process is finished as intended, and the effort stays on time. The facilitator understands that the outcome should include schedules to be performed by the maintenance personnel, operating procedures for the users of the equipment, and proposals for one-time changes that must be made to the design of the equipment or the way it is operated. The latter addresses the situations where the equipment could not deliver the desired performance in its current state.

Senior management plays the role of auditor and ensures that the review is sensible and defensible. This includes an agreement of both the definition of functions, performance standards, the identification of failure modes, the description of failure effects, the assessment of failure consequences and the selection of tasks. This makes sense since they are ultimately responsible for the success or failure of the process. Once management blesses

and approves the review, the changes are documented for all to understand and to comply with. This includes changes to maintenance planning and control systems as well as Standing Operating Procedures (SOPs). Proposals for modifications are dealt with by the engineering organization. [Ref. 6]

F. RCM ACHIEVMENTS

The outcomes of the RCM process are a means to an end. Specifically, they should fulfill the maintenance expectations discussed earlier in this chapter. RCM achieves these goals through improved operating performance, more cost effective maintenance, greater environmental and safety integrity, and longer useful life of expensive equipment. It also provides a comprehensive database, greater motivation among participants, and better teamwork. The major feature of RCM is that it provides a step-by-step program for tracking all the achievements at once while involving everyone who has anything to do with the equipment in the process.

The RCM process has proven to yield quick results which translate into timely, cost effective change that any organization could take advantage of. For example, if RCM is applied to a legacy system with an established maintenance policy, it generally reduces fully developed scheduled maintenance tasks by between 40-70%, reduces material disposal fees by between 30-50% and reduces the total number of maintenance man-hours expended by 35-60%. [Ref. 14]

Additionally, RCM has been refined to improve both clarity and user-friendliness. This allows for the

principles to be successfully applied by those who are not highly experienced or academically trained maintenance management experts. It is far more than a set of engineering principles, it is designed to empower and enhance the skills of the maintainers and users as well as provide a foundation for positive organizational change.

G. ARGUMENTS AGAINST RCM

There are a growing number of consulting organizations in commercial industry that claim to provide the "best" reliability centered maintenance processes. Many attempt to show that their particular process is better than the others because it is "faster" or "streamlined." Some are simply watered down versions of Nowlan and Heap's RCM while others take completely different approaches at providing their clients "better" reliability for less effort and cost.

While RCM II has been extremely successful (it has been applied in over 1,400 organizations in more than 40 countries), RCM in general is not always successful. It has failed in approximately one third of the organizations where it has been tried, either because the organizations concerned did not derive the benefits that they hoped to or the RCM initiative collapsed before it could yield much in the way of significant results. This does not sound like an exemplary track record but two-thirds success is at least as good as, if not better than, the success rate achieved by major organizational change initiatives in general. [Ref. 8] The key point is that none of the initiatives failed for technical reasons. Without exception, the initiates failed for organizational reasons.

One common reason for RCM failure was the principal internal sponsor of the initiative quit the organization or moved to a different position before the new ways of thinking embodied in the RCM process were institutionalized. Another common reason was between the internal sponsor and the consultant; neither could generate sufficient enthusiasm for the process for it to be applied in a way that yielded results. Again, both of these reasons for failure revolve around people caring whether the process is a success, but not because of the process itself. [Ref. 15]

Since maintenance managers look mainly at tangible returns rather than the projected expected returns of carrying out RCM, the time it takes to see results is important. RCM consultants advertise that, if properly trained people working under the direction of a skilled facilitator correctly apply RCM, and the project has been properly planned before it starts, it usually pays for itself between two weeks and two months. In some cases the payback period has been measured in days and sometimes one or two years, but the norm is weeks to months. [Ref. 8] Competitive maintenance management programs such as Planned Maintenance Optimization (PMO2000) claim that, you will have these (hazardous problems) under control in one year, but if you use RCM it will take you six years. [Ref. 8] The facts simply don’t support this generalization.

There is also the debate that RCM is only worth applying to high-risk industries such as petrochemicals, oil or gas and goes further to suggest that it would be a waste of time to apply RCM to mature plants or equipment.

Once again, the facts do not support this generalization since there are numerous examples in which RCM has led to successes in small (low risk) contexts as well as mature established industries.

The lack of enough precise failure data for an engineering analysis may lead interested companies to believe that RCM can not be applied. The reality is that, most of the organizations that apply RCM lack precise historical records about failures and some of the most successful users have had none at all. [Ref. 16] RCM is able to overcome these obstacles by recognizing that most of the information needed to conduct a thorough analysis already exists in the minds of the operators and maintainers of the equipment on a daily basis. RCM is designed to seek and capture the experiences of these people in systematic and highly effective fashion. RCM also recognizes that the information needed to make sensible and defensible decisions will not always be available. In this case, if the consequences of uncertainty were too intolerable, then the design or operation of the process would need to be changed.

Planned Maintenance Optimization (PMO) seems to be the greatest competition to RCM. The problem with PMO is that it starts not by defining the functions of the asset, which is specified by SAE JA1011, but starts with the existing maintenance tasks. Users of this approach are then asked to try to identify the failure mode that each task is supposed to be preventing and then work forward again through the last three steps of the RCM decision process to reexamine the consequences of each failure and hopefully to

identify a more cost effective failure management policy. This approach is similar to other emerging derivatives of RCM. These include "Streamlined RCM" or "RCM in Reverse" which are derivations of the Nowlan and Heap RCM that attempt to apply only some of the RCM steps, and "back-fit" RCM, which attempts to apply the RCM concepts in reverse. [Ref. 8]

Since we understand the phrase, "time is money," the proponents of PMO claim that their process achieves the same results as RCM in much less time. Analysis indicates that they produce nothing like the same results as RCM, but they contain logical or procedural flaws which can increase risk to an extent that overwhelms any small advantage they might offer in reduced application costs. By following the PMO process, companies take on the additional risk that any of the assumptions required might be wrong and thus the small advantage is ultimately lost. [Ref. 8]

The bottom line is that the users who are concerned about the cost effectiveness of the maintenance management process they are considering, would be well advised to take the same measures they would take when embarking on the use of any other new process. Decide what cost effectiveness metrics are important, then check the track record of that process and see what kind of experiences others have with it. [Ref. 8]

H. DOD POLICY ON RCM

The RCM process has been applied to thousands of organizations spanning nearly every major field of endeavor. Though the military is included in a few of the successes, it is evident in the correspondence from senior

military leadership that there has been a lack of aggressiveness in pursuing all opportunities for its application. Besides overcoming cultural change, perverse incentives, and a lack of adequate funding, the RCM process requires determined support from senior military leadership. [Ref. 17]

There is a lot written on DoD acquisition reform and in many cases, the buzzword "reliability" can be easily found. The issue is that there are numerous generalities that mention how important reliability is, but little reference as to how to achieve it. Though the scope of this research does not include the strategies Program Managers should implement to maximize reliability, there are military examples in which RCM has accomplished the same reliability success that is so prevalent in commercial industry.

With the lack of specific DoD-wide guidance and regulation on RCM, it appears that all military applications of the RCM process have been initiated by proactive individuals who have taken the time to learn about the process and realized its potential in their organization. Each branch of service has had success. The Navy utilizes the RCM process to incorporate reliability into its new procurements and in-service management of aviation assets [Ref. 18] as well as its ships' maintenance [Ref. 19]. The Air Force objectives in implementing RCM are to reduce engine related Cost Per Engine Flying Hour (CPEFH) while continuing to ensure aircraft engines are safe and reliable. [Ref. 20] The Army recommends RCM techniques to coordinate maintainability design efforts

with maintenance planning in its acquisition process, [Ref. 21] as well as calls for RCM logic to be used by all commands and activities to determine a maintenance program for fielded equipment systems. [Ref. 22] The Coast Guard appears to be the first military organization that has successfully applied RCM to the acquisition of a complete asset in the development and construction of the USCGC *Healy*. [Ref. 23]

While the Marine Corps partially defines RCM in its *Acquisition Procedure Handbook* [Ref. 24], there are no references to RCM in any other current service specific orders. Although Marine acquisitions are guided by Secretary of the Navy Instructions (SECNAVINST) that briefly mention RCM as part of acquisition maintenance planning [Ref. 25] and supportability analysis, [Ref. 26] RCM is not mandated in either of these references. Moreover, RCM has not been incorporated into any USMC ground program because there are no USMC regulations or procedures governing RCM. The Advanced Amphibious Assault Vehicle (AAAV) Program Manager’s decision to apply RCM to the program has been the result of proactive individuals guided primarily by initiative and the acknowledgement of a successful commercial business practice. In the absence of specific guidance to the application of RCM to an acquisition program, AAAV has chosen to apply RCM because of its tremendous potential as will be examined in the following chapter.

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III. RCM APPLICATION IN THE AAAV PROGRAM

A. INTRODUCTION

As mentioned in the previous chapter, the Marine Corps has no specific reference governing the application of Reliability Centered Maintenance (RCM) to the maintenance or acquisition of USMC ground programs. It is interesting to note that without the initiative of key personnel involved in the AAAV program, RCM would have likely remained unnoticed. This chapter will introduce the AAAV program, examine the reasons the program chose to utilize the RCM process, how RCM was applied, the obstacles that were faced, how these obstacles were overcome, the benefits realized and finally the long run expectations.

B. ADVANCED AMPHIBIOUS ASSAULT VEHICLE

The United States Marine Corps' Advanced Amphibious Assault Vehicle (AAAV), under development by the Direct Reporting Program Manager, Advanced Amphibious Assault (DRPM-AAA) and General Dynamics Amphibious Systems (GDAMS) will replace an Amphibious Assault Vehicle (AAV) that was designed in the late 1960's and subsequently fielded by the Marine Corps in 1972. The AAAV program is the Marine Corps' number one priority ground weapon system acquisition program, as well as the only ACAT 1D program managed by the Marine Corps. The AAAV will allow the Navy and USMC to conduct operational maneuver from the sea, link maneuver in ships with maneuver ashore in all types of amphibious operations, and will provide a new capability in support of Expeditionary Maneuver Warfare. The AAAV will provide the capability to transport seventeen combat loaded infantrymen

over the water at speeds in excess of 20 knots, and once ashore, maneuver cross-country with agility and mobility equal to or greater than that of the M1 Tank. [Ref. 27]

The program began with the Concept Exploration (CE) phase in August 1988 and in 1996 entered the Program Definition and Risk Reduction (PDRR) Phase. During PDRR, three prototypes were built; each was fully capable of all modes of operation. As of this writing, the program is in the System Development and Demonstration (SDD) phase during which ten second-generation prototypes will be built and tested. The first AAAVs are expected to be issued to fleet units in mid-2007 and some 1013 vehicles will be built between then and 2012. [Ref. 28]

C. AAAV PROGRAM CHOICE TO UTILIZE RCM

In keeping with acquisition reform initiatives pointing to better business practices, and to ensure that the Marine Corps is delivered a supportable asset with the lowest possible life cycle costs, DRPM-AAA undertook an initiative to apply RCM as defined by SAE JA1011 and initially, chose John Moubray's "RCM II" for the AAAV. Moubray, Chief Executive of Aladon LLC, was invited to present a paper on his process at the Department of Defense-sponsored National Defense Industrial Association (NDIA) in St. Louis, Missouri in November 1999, and in attendance were both the AAAV Logistics Director and the Maintenance Officer. Representatives from NAVAIR and the Royal Navy followed Moubray's presentation; both extolled the power of RCM II and quantified the benefits of the process to their programs.

With only general references to RCM in Secretary of the Navy Instructions (SECNAVINST) and with no service specific guidance on the application of the process, credit must be given to the program Logistics Director and Maintenance Officer for the extent to which the AAAV program has applied RCM. Through extensive research and sincere dedication towards making the AAAV a reliable and maintainable asset, these gentlemen were able to prove to the Program Manager that the RCM process would pay great dividends on the AAAV prototypes. [Ref. 29] Shortly after learning about RCM II at the NDIA symposium, the AAAV program office awarded Aladon LLC a sole source contract totaling $150,000 for a pilot initiative in the application of RCM. This pilot was intended to demonstrate whether RCM was suitable for application to a prototype vehicle and to determine whether the investment in this process was worthwhile. The initial pilot training program began in October 2000 and consisted of training approximately sixty program personnel, training and certifying five RCM facilitators and examining key AAAV systems to demonstrate actual results. The pilot program also included facilitator mentoring, project technical support and presentations to senior leadership. [Ref. 30]

In retrospect, the program team members would have preferred to implement RCM during the Component Advanced Development phase. As it would be, two competitors had produced ¾ scale technology demonstrators (hydrodynamic and land test rigs) in order to prove their concepts. After evaluating the two companies, the program down selected to GDAMS because there was more confidence in their ability to design and produce the AAAV. The program recognizes that

RCM could have played an integral part in this evaluation process. [Ref. 28]

Additionally, the program took the ORD and used it to produce a system/subsystem specification (SSS). In some cases, the SSS was rather ambiguous, while in others, more stringent than the ORD. Had RCM been applied (particularly question 1 of the fundamental RCM questions that were described in Chapter II) to the SSS development process, it would have resulted in a much more granular document with far greater clarity and less chance for misinterpretation. The RCM team is confident that if their process had been used to analyze the systems at an earlier stage of the program, many of the “problems” identified during PDRR would have been avoided. However, since the pilot program was not initiated until late in the PDRR phase, three prototypes had already been designed, built and were operating. One prototype had been in testing for about eleven months, the second one was about 90% built and third was 25% built, so there was limited opportunity to influence the initial PDRR design through RCM. The design was what it was and all the hardware had been bought. [Ref. 28]

With three prototypes assembled and the program feeling the normal stresses involved in acquisition, the newly trained facilitators set out to convince themselves that this investment was worthwhile by conducting the first analyses on relatively simple systems with the potential for immediate payback. The Marine Drive Steering system was chosen as one of the first analyses to be conducted.

The recommendations that flowed from these initial analyses quickly demonstrated to the facilitators' the unique benefits of RCM. For example, during early testing, one of the prototypes was plagued with uncommanded steering events in the water. Although the designers were struggling to determine the cause of this, the Marine Drive Steering analysis revealed several failure modes that would contribute to the problem. Among them was corrosion in wiring harnesses and when this was corrected on the prototype, the steering problems were solved. During each of the pilot analyses, both facilitators and group members discovered that there was much more about the AAAV that designers, engineers, and technicians were not aware of, until RCM was applied.

Despite the goal of analyzing thirteen areas during the RCM pilot program by January 2001, only five analyses were completed. The complexity of the AAAV and its subsystems was not immediately evident, even to an RCM practitioner with more than eighteen years of experience with the process and as a result, not all of the targeted areas were analyzed. [Ref. 31]

Contributing to this problem was a lack of experienced facilitators. The RCM process, when properly applied by an experienced facilitator, averages about six completed failure modes per hour; however, this speed is generally not achieved until a facilitator has completed between three and six analyses. [Ref. 13] Nonetheless, the Program Manager was impressed with the dramatic results of the pilot program and in February 2001, a competitive contract for RCM training and mentoring was initiated. Several

organizations submitted proposals for the contract, but extensive and exhaustive research revealed that only Aladon's RCM II process was fully compliant with the SAE standard. Furthermore, although other bidders' processes had merit, none had ever been applied to a prototype. As a result, Aladon was awarded the second RCM contract for an additional $250,000. [Ref. 28]

Although GDAMS had never used RCM either, during negotiations for the SDD contract, they agreed to the Government's request to replace requirements to perform Failure Modes and Effects Analyses (FMEA) and Failure Modes, Effects and Criticality Analyses (FMECA) with RCM. As a result, contract hours originally intended for FMEA/FMECA were shifted to RCM.

In the beginning, there was resistance to the process since team members from both the Government and contractor thought, "We have already done a FMEA, why do we need to do RCM?" However, as the results of analysis became known and as the significant benefits of the process was revealed, growing numbers of program personnel actively sought to participate. The outputs from RCM analysis provided feedback to designers, logistics engineers, technical manual developers and troubleshooting developers, just to name a few. [Ref. 13]

D. APPLICATION OF RCM

When the program decided to use RCM in lieu to the traditional FMEAs, the program took the number of hours that would have been spent on FMEA and transferred them to RCM. As a result, the SDD contract has approximately 4500 contractor labor hours available for RCM analyses. Out of

eight system level analyses, the program has used 1263 hours with an approximate split of 421 for the Government and 824 for the contractor. These analyses represent about forty percent of those planned for the entire AAAV but have only used a little more than twenty-five percent of the available time that would have been used to conduct FMEAs.

RCM is incorporated into the integrated product team (IPT) process. Analyses have been completed in as little as three meetings for a simple system and as many as twenty-five for a complex system. Each meeting generally lasts for three hours and the analysis teams meet two or three times a week. Based on a forty-hour workweek, this equates to approximately twenty to twenty-five percent of each member’s time for each analysis. On occasion, meetings have been conducted on an eight-hour basis; however, this is the exception to the rule. Experience has shown that three-hour meetings are optimal in terms of productivity of group members. As the length of the meeting increases, productivity decreases because of the intense focus that RCM demands. [Ref. 28]

Each analysis calls for one facilitator who spends an average of one hour outside the RCM meeting for every hour spent inside. This time is typically spent typing information, generating reports, consolidating data, and preparing for the next meeting. During an assigned analysis, the facilitator could spend approximately forty percent of his or her time on the analysis. The program also has one RCM practitioner who spends sixty percent of his time mentoring facilitators, conducting technical audits, and providing training. It is noted that the

analyses are sporadic, ranging from none being conducted to as many a four at one time.

Though RCM training speeds up the analysis, the program found that the training was not absolutely necessary. The first few days of analysis with untrained personnel merely take longer than they should because the RCM process has to be explained along the way, but the quality of the analysis is the same because the facilitator keeps the meeting focused on the objective. With that said, retraining is not necessary either, since retraining essentially occurs while members participate in the analysis.

The outputs from an RCM analysis are numerous and include a comprehensive list of failure modes and their effects, recommendations for preventive maintenance, and recommendations for changes in design. In RCM II terms, design changes are not limited to physical changes to an asset. Design changes can apply to changes to process and procedures changes to training methods and changes in technical documentation. Recommended changes may also include changes to critical design reviews, required delivery documents, functional flow diagrams and a number of other things that engineers use to methodically weed through problems.

After an RCM analysis has been completed, the facilitator consolidates the data contained in both information and decision worksheets and turns the entire report over to the system engineer who is responsible for getting the appropriate people together for a management audit of the analysis. This management audit ensures that

the information worksheet is technically correct and that the recommendations make sense. Management accepts or rejects each recommendation and develops an implementation plan for those accepted. The approved recommendations are entered into a Data Collection and Corrective Action Systems (DCACAS) and the IPTs are responsible for reviewing each approved DCACAS as well as taking appropriate action.

The DCACAS is a "checks and balance" system; therefore, after the IPTs have taken action, reliability personnel have to make a final approval before the DCACAS can be closed. Everyone in the program office essentially has access to the DCACAS database, ensuring that all information is easily attainable. Specific examples of DCACAS recommendations include future training requirements, additional personal protective gear, incorporating warnings or cautions into technical documentation, reevaluation of standard operating procedures (SOP), updates to technical manuals, setting testing limitations, and physical design changes. Personnel responsible for developing technical manuals have been able to simple "cut and paste" straight from the DCACAS, thus making their jobs more efficient. As of February 2002, the program had conducted eighteen RCM analyses that have resulted in more than 550 DCACAS. [Ref. 13]

RCM training will be more thoroughly addressed in subsequent paragraphs; however, as of February 2002, the program had conducted nine three-day RCM training sessions for well over one hundred DRPM-AAA/GDAMS AAAV team members.

E. RCM OBSTACLES

As anyone might expect with a new way of conducting business, there would be initial difficulties incurred in the application of RCM to a prototype military vehicle in a joint Government/contractor environment. Several difficulties were encountered, the most significant of which was obtaining buy-in from the management (both the Government and contractor) and the numerous IPTs that make up the program. Additionally, an extremely ambitious schedule and a very tight budget did not make for the best environment to experiment with a new process.

The DRPM-AAA/GDAMS AAAV development team is made up of more than twenty separate IPTs. Initially, it was difficult to determine exactly which IPTs should participate in an RCM analysis, but once that was resolved, it was equally challenging to get the right persons to attend due to scheduling pressures. Initially, many members perceived RCM to be “just another process” that someone directed them to support.

Once the specific IPTs and the appropriate personnel from each IPT were identified, the next challenge would be to get them to attend each meeting. Demanding schedule pressures coupled with the usual under-manning that exists in almost every acquisition program made it difficult for some to rationalize spending time in the RCM meeting room. Without the right people present, the process was slowed down because the expert would have to be located to answer certain questions. Prior to any firsthand evidence that this process was worthwhile, it was difficult for many to accept that RCM was indeed a powerful tool that would save much more time than was invested into it.

Further adding to the resistance was the view that RCM had already been applied since the traditional Failure Modes and Effects Analysis (FMEA) had previously been performed on many of the AAAV systems. Though a FMEA answers questions three and four of the RCM process, failure to address the other five prescribed RCM questions makes the traditional FMEA inadequate. RCM analysis accuracy and robust results would eventually prove that this process was not the duplication of effort as originally perceived but instead, was a valuable addition to the program's acquisition toolkit. [Ref. 34]

F. OVERCOMING RCM OBSTACLES

The first step in overcoming obstacles to the RCM process was obtaining senior leadership buy-in. As with any controversial or new process, if the leadership does not publicly show support, the process will fail. The Program Manager understood the benefits of RCM and ensured the process was adhered too by supporting the RCM training and acknowledging the results of each analysis. [Ref. 28]

With support from management, the originally trained facilitators demonstrated remarkable persistence in ensuring the RCM program continued to move forward. Faced with the daunting task of proving that RCM worked, facilitators scheduled analysis and literally grabbed people out of their offices to participate in the review session.

Each RCM analysis comes with both a monetary and opportunity cost since it requires the full attendance by each participant for the entire analysis. During the analysis, each group member's routine duties and

responsibilities were either handled by another or put on the back burner. Most managers realized that their investment in the analysis was paying off since the results of the each analysis was so productive in terms of recommended tasks and proposed design changes. RCM was essentially making management’s job easier. Management’s acceptance and subsequent implementation of analysis recommendations provided the group members with a sense of empowerment, which further secured their support of the process.

The second step in overcoming RCM obstacles was accomplished through training. RCM training falls into one of three categories. The first is training personnel to be potential analysis group members. This training package is three days in length and provides group members with a common understanding of the RCM concept and a common language with respect to RCM. Experience in both the AAAV program and within the Aladon network has shown that analyses proceed much more efficiently if all group members have had this training. [Ref. 13]

A trained facilitator leads each RCM analysis. Facilitator training is ten days long and provides each student with the basic skills required to schedule and conduct both the RCM analysis and the management audit of the analysis. A prerequisite to facilitator training is attendance in the three-day course and following their ten-day training course; facilitators are mentored as they apply the RCM process. Mentoring reduces the learning curve for the new facilitator as he or she has immediate

on-site support for all the issues encountered in applying RCM for the first few times.

As one of the program goals was to become self-sufficient in the RCM process, AAAV took an extra step in having one of their persons trained as an RCM practitioner. Practitioner training is fifteen days in length and upon successful completion; the practitioner is certified and able to train group members and facilitators. The AAAV program has one trained practitioner and plans to train to two more over the next year.

As more IPTs sent people to the group member training, word of mouth support for RCM began to spread. This led to a number of people requesting a seat in the next RCM class. Some of these people were sincerely interested in learning about the process while others attended the classes as an opportunity to discredit the process. None of the latter succeeded and most became converts. [Ref. 28]

The third hurdle in overcoming obstacles to RCM implementation was ownership. Buy-in to the RCM process began very slowly, but with the publication of each new analysis and as each of the review groups saw their recommendations adopted, members began to show interest and acceptance of the process began to spread. The RCM process provided a genuine sense of empowerment to the group members while quickly broadening their understanding of the AAAV. Even as a trained RCM practitioner, the AAAV Maintenance Officer would be astonished by the overwhelming feedback the RCM-trained team members provided him:

> As RCM education expanded, more and more people began to wonder if it could solve their specific problems. In some cases, the problem was maturation of a new design. “Will this design work as intended?” “Will it do what the user wants it to do?” “Is this the best solution to an identified design problem?” “Will this design interface with other subsystems as intended?” In other cases, the questions were specific. “Can RCM help us determine what the embedded logistics administration system (ELAS) should do?” “Can RCM examine the best way to design and implement a life cycle management information system (LMI)?” And in still other cases, “Can an RCM analysis provide supporting documentation for a ‘safe and ready for test’ certification?” “Can this process help us ensure that testing of a carcinogenic material is conducted safely?” In each case, the RCM process quickly and thoroughly provided the information each group was looking for and resistance to the process further diminished. [Ref. 32]

Collocation would also aid in overcoming RCM obstacles since the team members from both Government and contractor interacted with each other on a daily basis. This familiarity inspired face-to-face meetings that ultimately addressed RCM issues promptly. Collocation fostered open communication that helped to build trust and mutual respect, which are essential, for teamwork environments required by both the IPT and RCM process. [Ref. 34]

G. QUANTIFYING THE VALUE OF RCM

It is difficult to quantify the results of RCM because the AAAV is a brand new system; as a result, true “savings” or “loss avoidance” cannot be calculated. As RCM is being applied to the AAAV while it is in the prototype stage, there are no baselines from which to calculate any reductions. [Ref. 30] The AAAV is not an evolution of the

current AAV design; but a revolutionary change in virtually every respect. Even though these two warfighting systems will perform similar missions, they are definitely not the same.

In the context of the AAAV, reliability is more than simply ensuring the vehicle has low life cycle costs, it has to do with taking care of Marines by ensuring the vehicle performs the way it is designed. Every time a change is made that affects safety, then a potential life has been saved. Since AAAV is designing out failures before they occur, the program will never know how much money or how many lives RCM will have saved. The generally accepted thought is that fewer Marines are likely to be injured or killed as a result of the recommendations made from the RCM analyses. The following paragraphs attempt to quantify significant recommendations that were the direct result of RCM analysis and that would have otherwise possibly gone unnoticed.

While analyzing the Power Generator system, the group found that the electrical boxes were designed to be easily unhooked to allow for quick exchange and troubleshooting. If the power was not disconnected from these boxes prior to removal, there was a very high risk that there would be a short to ground or an internal short in the cable due to the delicacy of the five-volt system. Additionally, since this system is set up in a token ring arrangement, a short anywhere in the path would result in everything in the box burning up. This seemed intuitive, but there were instances in which the prototypes burned these boxes because disconnecting the batteries was a cumbersome

procedure that was often omitted. The RCM analysis recommended that the simple procedure of ensuring the batteries were fully disconnected eliminated the burning of the electrical boxes. Furthermore, the analysis recommended a design change that resulted in a much more efficient method to disconnect the batteries.

During the same Power Generator analysis, the group also discovered that there was a software reset toggle switch among the four other switches that controlled power generation. The engineers had believed that the crew required a reset switch that could be activated in the event of software problems. This same switch was now causing problems. First, if the switch failed in the closed position the vehicle would not start. Second, if the toggle was tripped while the engine was running, the vehicle would shut down. Starting the vehicle is like booting a computer; it takes between three to five minutes to start. The engineers may have been correct in assuming that the Marines would need a software reset button, but failed to consider the operating context of having Marines in Mission Oriented Protective Posture (MOPP) gear with packs and all their equipment. With the added physical restrictions of wearing MOPP gear in a confined area, the crew might inadvertently bump into the switch, thus making accidental activation of the reset button highly likely. The group simply recommended that the switch be eliminated and that the existing switch be used for egress lighting.

During the Power Distribution analysis, the group discovered that an electrical failure might affect the scroll of the automated maps that the crewmembers use to

navigate. In an over the horizon (OTH) water march of up to twenty-five miles, this could result in a vehicle getting lost. The group recommended that the crew receive OTH instruction (dead reckoning and celestial navigation) reinforced with competency-based training. The designers had not thought about how the Marines would deal with that situation.

During that same Power Distribution analysis, the group found several failure modes that had to do with losing power in the surf. They realized that if power was lost at this point, the waves would batter the vehicle and everything that was not lashed down would become a flying object that could potentially injure or kill someone. The engineers had never thought about any significant measures for lashing to protect the embarked Marines aboard this vehicle. On the old AAV, the Marines hung their gear on bustle racks located on the outside of the vehicle. With the AAAV they cannot do that for signature reasons and because gear would be likely to be ripped off. The Marines have to store their gear between sponsons, which are just open spaces. The group recommended that “spider nets,” similar to those found in the trunks of cars to prevent groceries from splashing about be installed to contain the packs and equipment in the event of sudden stops or rollovers. While the idea of putting spider nets in the AAAV seems unrelated to a Power Distribution analysis, the RCM process precipitates this kind of analysis.

During the Hydraulic analysis, the group discovered that when changing from transition to water mode or vice versa, there are several appendages that must be

hydraulically moved. The RCM analysis revealed that once this automatic sequence was started, there was no provision for the driver to stop the deployment. The group visualized these flaps deploying and possibly striking a submerged object. The group recommended that the software design be changed to include an abort option after the selection of the appendage stop button.

Prior to prototype testing at Marine Corps Base, Twentynine Palms, the RCM process was used to look at the vehicle in the operating context of being operated by Marines, carrying infantrymen in the harsh desert environment. The entire system was analyzed for potential safety problems. The result was the identification of one hundred twenty failure modes that could directly contribute to someone being killed. Based on the RCM group recommendations, an SOP was developed that included test limitations, changes were made to the technical manuals, and several changes were made to the design to improve safety during operations in the desert. As a result of further analysis for the same desert testing, the group recommended that the cooling system be refurbished. Previously, the vehicle had experienced one leak for every forty-five minutes of operation. As a result of design changes, the vehicle returned from several months of testing with no leaks and no one was injured or killed.

An analysis was conducted on the new bow flap design for the program’s first System Development and Demonstration (SDD) vehicle. The bow flap had never been built or used and since the designers were close to being done with it, the program office wanted to apply RCM before

it was completed. The group came up with a number of recommendations that would increase the chance that the bow flap would work the first time. Most of the recommendations dealt with testing and characterization of the new flap, which, if implemented, would provide them with both a better feel for operations in the open ocean and the opportunity to make the bow flap more reliable prior to testing.

There are numerous examples where RCM analysis has led to changes intended to increase the vehicle reliability, but as these previous examples showed, RCM was also instrumental in analyzing human factors, safety, software design and even designs that hadn’t been completed. [Ref. 34]

H. LONG RUN EXPECTATIONS

The long run expectations of the impact of applying RCM in the acquisition of the AAAV are that the Marine Corps will receive a reliable asset that will perform its specified missions safely as designed while not being a burden to maintain. RCM makes the program look at the effects of failure to ensure that each failure management policy is sensible. Effects are always looked at from the worst-case perspective; that way, if something less than worst case happens, the Marine crew and their vehicle should be unharmed. If the worst case does happen, the consequences will not be a surprise because they will have been anticipated and mitigated to the extent possible.

Based on the results experienced by both NAVAIR and the Royal Navy, the program expects RCM to provide at least a thirty to forty percent reduction in the amount of

scheduled maintenance compared to that being performed on its predecessor, the AAV7-A1. At the same time the amount of consumables used and hazardous materials generated will also decrease. Availability is expected to be higher so there will be improved readiness for less effort. RCM data will also help to determine the optimal amount of component sparing needed to maintain readiness goals.

The AAAV program intends to continue to apply RCM throughout the remainder of the acquisition. The application of RCM has had clear benefits. The sum of the analyses will play an integral part in determining the final maintenance plan. The program office intends to continue applying RCM throughout the life of the AAAV. Once the system is fielded, there will be a point where the level of effort decreases, but it should not stop entirely because people will always want to make changes. As long as the planning or the potential exists to make changes to the platform design, RCM should be part of the process, because it provides a structured approach within which to evaluate those changes.

IV. ANALYSIS OF RCM AND ITS APPLICATION IN THE AAAV PROGRAM

A. INTRODUCTION

This chapter discusses the results presented in Chapters II and III. The focus of the analysis is on the primary thesis question: What have been the results of applying the RCM process in the acquisition of the Marine Corps AAAV and what are the reliability expectations associated with the further development, production and deployment of the AAAV? The analysis will include the reasons for success in the AAAV program, the benefits of RCM and finally the negative considerations of RCM.

B. WHY HAS RCM WORKED FOR THE AAAV PROGRAM?

It is the author's opinion that RCM has worked for the AAAV program due to a strong commitment from the program leadership, highly proficient facilitators, mentoring, in house RCM training, organizational structure and location, and the use of IPTs.

1. Program Leadership

Senior leadership is probably the most important factor in RCM, followed closely by persistence. Without the support from top, culture change will not occur and no process will survive. Colonel Nans' support of RCM and his guidance to the AAAV program's senior leadership that the process was worthwhile were instrumental in getting RCM off the ground. Similarly, the first groups of facilitators (the "RCM pioneers at AAAV") were extremely persistent in scheduling analysis and rounding up people to participate in the review groups. Without this persistence, the

process would have languished and eventually died. [Ref. 28]

2. Facilitators

Without properly trained facilitators to guide each analysis, RCM would have failed. The facilitators are the experts in RCM and thus ensure the entire process is understood and applied by the group. The program found out early that not everyone is cut out to be a facilitator. The facilitator must also have the support of their leadership, especially if this billet is a collateral duty. Collateral duties often lead to conflicts in priorities since the facilitator may feel competing pressures to complete both an analysis as well as the regular assigned duties. In this case, there is the danger that one or both will suffer. Leadership must also be patient since there is a learning curve for a facilitator to climb before proficiency and quality are achieved. [Ref. 13]

3. Mentoring

Mentoring helps to alleviate the challenges facilitators have to face. The AAAV program maintains monthly ties to Aladon to ensure its facilitators are performing as intended by RCM II. The bottom line is if you do not understand the logic, then you can’t apply the process. Mentoring assists the facilitators’ in learning how to better focus and ensure the process is performed as required. This is essential when working with inexperienced RCM team members who “don’t know what they don’t know” and the probability of “getting it wrong” is very high. [Ref. 13]

4. Training

Though the program has found that RCM training is not a prerequisite for a member to participate in an analysis, the training does speed up the analysis process. Additionally, the in-house RCM training has added a personal touch to use of RCM. Facilitators can use specific examples from the previous AAAV analysis to add to the generic examples provided with the course. This is usually the first opportunity to address the skeptics. In a few cases, the hardcore doubters are not convinced of the power of RCM until they complete an actual analysis, but the training is essential in ensuring the analysis flows smoothly. After the training, the non-believers at least understand the process they will go through, regardless of their faith in it. [Ref. 13]

5. Organizational Structure and Location

The collocation of Government and contract personnel greatly facilitates the use of IPTs in the AAAV program. Since RCM fits so well into the IPT process, this collocation further strengthens the RCM process. All the group members know each other since they interact on a daily basis. This fosters rapid and open communication. All program personnel can be immediately aware of proposed design changes or if something is not working right; personnel from either side of the program can walk to the other’s office to resolve an issue. [Ref. 34]

6. Integrated Product Teams

One of the cornerstones of the DoD acquisition reform effort that was initiated in the mid 1990s was the move to

operate in Integrated Product Teams (IPTs) rather than functional stovepipe organizations found in many DoD programs. IPTs are a great idea in that they involve all the necessary mix of people to make sound technical decisions. In the case of the AAAV program, there was still a lot of wasted effort in IPTs. That is, even with qualified technical personnel, activities might be performed two or three times over because they did not get things right the first time. RCM fits perfectly into the IPT forum because both processes require a group of specialized personnel coming together to solve problems. RCM just takes it one step further by providing the needed focus that gives IPTs a big advantage towards getting it right the first time. There is a lot of positive feedback from the IPT members exposed to the RCM process. It would have been more difficult to get RCM off the ground without the current IPT process already in place. [Ref. 28]

C. BENEFITS OF RCM

The benefits of RCM II are summed up by John Moubray's book, Reliability-centered Maintenance:

> Widely recognized by maintenance professionals as the most cost-effective way to develop world-class maintenance strategies. RCM leads to rapid, sustained, and substantial improvements in plant availability and reliability, product quality, safety, and environmental integrity. [Ref. 6]

Interviews with personnel involved in the AAAV's RCM program have indicated that RCM II has provided similar benefits in many applications around the world. In particular, program staff has gained a much more granular understanding of exactly what each IPT wants in terms of

performance from each sub-system. Additionally, IPTs have a much clearer understanding of the effects of each failure mode and as a result, have achieved a better focus on where to spend maintenance time. RCM II has provided a structured approach for understanding and analyzing proposed design changes and provided an efficient process for quickly addressing operational risk. In spite of traditional thinking that suggests massive amounts of usage data are required to analyze maintenance, RCM II has proven its value in the absence of such data and proven that RCM can be usefully applied as late as the System Development and Demonstration phase.

1. Better Understanding of Failure Mode Effects and How to Minimize Them

As mentioned in Chapter II, once functional failures have been identified, RCM identifies all the events that are reasonably likely to cause each failed state. We know these events as failure modes and once they are identified, then it is possible to consider what happens when they occur, assess the consequences, and decide what should be done before they actually happen. With the AAAV, the examples of the software-reset toggle switch removal, the need for over the horizon (OTH) training for crew, the installation of spider nets, and the abort option for transition to and from water mode are all examples of identifying failure modes (many before they actually occurred) and managing them proactively. [Ref. 34]

2. Better Focus on Where to Spend Maintenance Time

The objective of a successful preventive maintenance program should be to prevent or mitigate the consequences of failures and not to prevent the failures themselves.

RCM analyzes the effects or consequences of the possible failure modes and evaluates their effect on safety, the environment, operations, or cost. Since the program is utilizing RCM in the development of the AAAV, program staffs are more likely to define functions in the proper context, and subsequently develop a practical preventive maintenance program that will ensure the system performs the way it was intended. Additionally, once the analysis results have cleared the DCACAS process, technical documentation is updated thus ensuring quality in future operational and maintenance publications.

3. Structured Approach for Understanding and Analyzing Proposed or Needed Changes in Design, Processes and Procedures

SAE JA1011 states that in order to be called "RCM," a process must obtain satisfactory answers to the seven questions presented in Chapter II. Since these questions must be asked in order, there is little chance of logical or procedural flaws in the analysis. With the AAAV, these potential flaws could lead to safety or environmental accidents that could contribute to injuries or death of Marines or substantial environmental damage. The electrical box example from the Power Generator system analysis demonstrates the benefits of following the structured approach of RCM. Additionally, it was evident in the overwhelming feedback from RCM-trained members to the program Maintenance Officer that the structured RCM process is not only easy to understand, but easy to adapt and apply to different designs, processes, or procedures. [Ref. 34]

4. Common Point of Understanding for Addressing Operational Risk Areas that Will Result in Improved System Readiness

One of the pillars of RCM is safety. If the consequences of failure include either safety or environmental effects, then redesign is compulsory. In the context of the AAAV, reliability is more than low life cycle costs. Reliability also has to do with taking care of Marines by ensuring risk is minimized. The inclusion of a spider net for storing equipment is one example which demonstrates that even though the RCM analysis was focused on the Power Distribution system, the RCM trained team members were able to recognize a potential hazard and recommend a design change to mitigate the risk. [Ref. 34]

5. Timely Benefits

As discussed in Chapter II, if RCM is correctly applied, results are quick to follow. Success is even more likely to come to those who thoroughly plan as well as carefully consider how and by whom the analysis is performed, audited and implemented. Though the AAAV program failed to complete the proposed number of analyses in their original pilot program due to the underestimating of the system complexity, they did experience immediate results from the analyses completed. With the example of the first analysis of the Marine Drive Steering system, the team was able to solve the uncommanded steering problem that had not been recognized until then. [Ref. 34]

6. Never Too Late to Apply RCM

As discussed in Chapter II, RCM II has been very successful in that it has been applied to over 1400

organizations in more than 40 countries. Since RCM II is a zero based process, it requires no preliminary failure data to conduct an analysis. The concept of accurately analyzing mechanical systems without the perceived benefit of extensive failure data and past maintenance history has been proven by RCM II. Some would argue that its impossible to accurately analyze systems before actual performance data is accumulated and because of this, would further suggest that RCM cannot be applied in the early stages of development. However, because of its proven track record in both civilian and military applications as well as the appeal of being zero based, (appealing because in PDRR, the program had virtually no maintenance history) the AAAV program initiated the RCM process late in the PDRR phase. [Ref. 28]

As described in Chapter III, the RCM teams were surprised by the recommendations that flowed from their analyses. Given the immediate success in spite of its "late" application, the AAAV program can only speculate as to what greater impact RCM may have had on the program if it was initiated earlier in the program. Future acquisition programs may want to consider the potential advantages of being able to influence the asset design early enough to avoid costly mistakes and before a single drawing is released to a vendor for production. Just as the program has demonstrated that it is never too early (through their successful analysis of the bow flap design) to apply RCM, the AAAV program has also demonstrated that it is never too late (regardless of the fact that the prototypes had been designed, built and were operating by

the time RCM was introduced) to apply RCM and reap both short term and long term benefits. [Ref. 34]

D. NEGATIVE CONSIDERATIONS OF RCM

Though RCM appears to be on firm ground with the AAAV program, there are drawbacks that should be taken into consideration. There are financial and opportunity costs involved in the process, there is the temptation to shortcut the process, and it is difficult to obtain buy-in.

1. Financial Cost

RCM costs money to implement. RCM II is the proprietary intellectual property of John Moubray and it is not free. Some people would look at the price tag and be turned off. The initial pilot program, which included technical support and training facilitators, cost the program $150,000 and the subsequent contract to continue the technical support of analysis and train practitioners was an additional $250,000. Though these costs appear substantial, one must consider them in the context of a multi-billion dollar program that will produce more than one thousand AAAVs, each costing around five million dollars. RCM has already paid for itself in the short term in many ways described in Chapter III, but in the long run, the program office expects that RCM will pay for itself many times over. [Ref. 28]

2. Opportunity Costs

Besides the direct monetary costs, there are also opportunity costs that might not have a specific price tag associated with them, but nonetheless will cost the organization in terms of personnel availability and short-

term productivity. As discussed previously, RCM analyses take time. Acquisition programs do not historically have a lot of “spare” time, so something has to give. All of the group members and facilitators have other responsibilities, so there are not any personnel who are solely dedicated to RCM. In order for the process to work as intended, Government and contractor leaders must adjust schedules and demands to account for the time their people spend on RCM analysis. [Ref. 28]

At the AAAV office, the leadership has this understanding and accepts this inconvenience as an investment that will pay off in the future. For example, as a result of RCM analyses, technicians supporting the vehicle gained an in-depth understanding as to how, exactly, the system works and more specifically, what effects certain failures have on the system. As a result of this increase in their knowledge, they were able to diagnose and repair the vehicle much quicker, thus saving expensive test site time. Moreover, in addition to the reduction in repair times measured by the program’s reliability personnel, RCM recommendations led to a decrease in induced failures as discussed in Chapter III. Because of the details contained in the RCM information worksheets, technical manual developers are able to “cut and paste” information, as opposed to conducting interviews with various designers. Additionally, RCM analyses of “virtual” designs uncovered flaws that were corrected before designs were released, thus avoiding the tremendous expense of building the “wrong” component. [Ref. 34]

3. Temptation to Make Shortcuts in the RCM Process

Though the AAAV program leadership and team members understand the importance of conducting RCM correctly, step by step, it would be very tempting to shortcut the process to save both time and money. This is especially tempting when there are so-called expert consultants advertising the same results in “much less time.” However, the RCM process is surprisingly fast, if properly applied and facilitated. Shortcutting the process, by adopting one of the derivatives of RCM discussed in Chapter II, may initially appear to save time, but considering the possibility of disastrous consequences along with the threat of having to redo an analysis after an accident, then doing it right the first time is the only logical choice. [Ref. 8]

4. Obtaining Buy-In

The AAAV program overcame the buy-in issue, but it must be stressed that, initially, this was a difficult obstacle to overcome. Programs that choose to apply RCM to their processes and systems must be prepared to face this challenge or RCM will not be successful. Most of the buy-in challenge can be attributed to the necessary culture change in the acquisition profession from standard FMEAs to RCM, since there appears to be duplication in effort to those unfamiliar with what RCM really is. All of the points made in section B of this chapter worked together to overcome these types of obstacles and the successes from RCM thus far have helped institutionalize it in the AAAV program. If any RCM results had been unsuccessful, there is a good possibility that RCM would have never been accepted within the AAAV program office. Buy-in will likely be a difficult factor to overcome in future programs. [Ref. 34]

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V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

The objective of this research effort was to examine the program decision to utilize Reliability Centered Maintenance (RCM) in the Marine Corps Advanced Amphibious Assault Vehicle (AAAV) program. The goal was to determine what impact this decision has had on the AAAV program, the future implications of the decision, and to determine if this decision could benefit other defense acquisition programs.

Background information on RCM was presented followed by a review of the RCM application in the AAAV program. This chapter will draw conclusions from the research effort and subsequent analysis that has been presented. Recommendations will then be made as to how lessons learned from the AAAV program may be applied to other acquisitions programs. Finally, areas for further research will be presented.

B. CONCLUSIONS

1. RCM Provides a Sound Understanding of the AAAV as a System

RCM is more than just a process that leads to an effective maintenance program. The application of RCM in the acquisition of the AAAV has led to better system performance through more complete understanding of systems, to include increased awareness in risk, safety and environmental issues. By simply answering the seven RCM questions in a group led by a trained RCM facilitator, as prescribed by SAE JA1011, each IPT can potentially gain a

more complete and in-depth understanding of the AAAV as a system. Because RCM requires a disciplined, focused and systematic approach to each analysis, there is less room for error and a greater chance of “getting the design right” the first time. This saves time and money, which any acquisition program should appreciate. Additionally, RCM II places great emphasis on safety and environmental awareness. The AAAV program has proven the risk awareness value of RCM by consistently identifying hazards or concerns that had been previously overlooked.

2. The Earlier RCM is Applied, the Greater the Benefits It Will Deliver

Since RCM is zero based (i.e., requires no historical maintenance data or history), the AAAV program team members would have preferred to apply the process earlier in the acquisition cycle to have better influenced the design and avoided costly problems that eventually surfaced. Since RCM was not introduced until late in PDRR, it was applied to three prototypes that had been designed, built and were operating. Regardless of the timing, program staff did find that RCM helped them better understand the AAAV and changes could still be made to influence increased readiness and availability, with decreased safety and environmental risks.

3. It is Never Too Late to Incorporate the RCM Process

As mentioned in the previous paragraph, RCM should be applied as early in the acquisition cycle as practical, but the AAAV program has also proved that RCM may be applied with good benefits, even after some of the initial system design work has been completed. Although the process is

ideally suited to analyze existing systems and equipment, it is equally powerful analyzing concepts and designs. Because it is a living program, RCM will help ensure that an effective and economical maintenance strategy follows AAAV through its life cycle.

4. The RCM Process is Not Limited to Just Maintenance Analysis

The name Reliability Centered Maintenance can mislead those who do not fully understand the definition of "maintenance" because it appears to limit the RCM process to the physical reliability of an asset. If "maintenance" is defined as "the process of ensuring that something continues to do what the user wants it to do," the scope of RCM expands dramatically. The AAAV program has found that RCM is a versatile process and has expanded its application to include analyzing human factors, safety, software design and even projects that were merely concepts. None of these were specifically related to the maintenance plan of a physical asset.

5. RCM Requires an Environment for Success

RCM succeeded in the AAAV program because of a strong commitment from the program leadership, highly proficient facilitators, effective mentoring, in-house RCM training, organizational structure and location, and the use of IPTs. Though some points are more important than others, all of these factors contributed to the successful implementation of RCM into the AAAV program. The committed leadership in AAAV provided the environment and the forcing function that resulted in imposition of all the other facets necessary for success. Leadership commitment is the *sine qua non*. My conclusion is that if the leadership will does not buy-

in and become the "champion" of RCM, the effort is destined to wither and die, and should not be started in the first place.

C. RECOMMENDATIONS

1. RCM be Institutionalized in DoD Acquisitions

The USD(AT&L) should mandate RCM, as prescribed by SAE JA1011, for all acquisition programs. The process has a proven track record in both civilian and military applications. Specifically, acquisitions can expect reduced program cost, savings in time, greater asset reliability, and increased safety and environmental awareness. Absent any DoD-wide guidance on how RCM should be specifically applied, the Commander, Marine Corps Material Command should take advantage of the expertise and experience of the personnel involved in the AAAV RCM program to develop a service specific policy on RCM. RCM is broader than but inclusive of Failure Modes and Effects Analyses (FMEA) and Failure Modes, Effects and Criticality Analyses (FMECA). Replacing current acquisition requirements to perform FMEA/FMECA with RCM should form the basis of the guidance. Consideration should also be given to establishing an RCM program office and applying RCM to fielded systems.

2. Apply RCM as Early as Practical in the Acquisition Process

RCM should be applied as early as practical in an acquisition program to successfully influence design and ultimately start with a "better" product. The Component Advanced Development phase appears to be a logical starting point, since this is where subsystems and components are demonstrated before being integrated into a system. RCM

should be used to ensure appropriate focus is given to understanding functions and standards of performance.

3. If You Cannot Apply RCM Early, It is “O.K.” to Apply It Later

Regardless of the current phase, acquisition programs should consider applying RCM to their program. AAAV has proven that later application of RCM still yielded significant benefits. Even if the asset is fielded, a RCM analysis will reveal opportunity for cost savings and improved reliability. The experience of NAVAIR (PMA-260) in applying RCM to support equipment is just one example of post fielding success.

4. In Addition to Maintenance Planning, Recognize the Power of RCM in a Broader Sense

RCM should be considered for more than just developing efficient maintenance programs. RCM can be used to test the feasibility of a new policy, gain appropriate risk awareness, examine software schemes, and confirm design concepts before any of these plans are set in stone. Once the RCM process is applied, the variety of potential applications becomes more evident.

5. Provide the Proper Environment for RCM Success

Those who embark on RCM must provide the proper leadership attention and support needed to overcome the challenges, primarily that of culture change of doing things differently, in order to achieve success. RCM requires a strong commitment from leaders, patience in training qualified facilitators, the support of mentors, and an investment in training. Additionally, those interested should ensure that the RCM process is in compliance with SAE JA1011, since there are organizations

that take advantage of the RCM name without providing the prescribed service.

D. AREAS FOR FURTHER RESEARCH

As a result of this research effort, the author has identified the following areas for further research that could be performed by NPS students:

- Once AAAV fielding is complete, consider reviewing the final RCM advantages and disadvantages and publish lessons learned.
- Research whether RCM could be applied to existing Marine Corps ground equipment. Consider a cost benefit analysis to determine the extent to which a selection of Marine Corps ground equipment would benefit from its application.
- Consider the feasibility of establishing a RCM policy and program for the Marine Corps. Does the Marine Corps have the infrastructure to incorporate RCM? Can the Marine Corps afford (or not afford) to institutionalize RCM? Who would be responsible and what would it take?
- Examine other programs experience with RCM. Can a consensus be drawn that would support institutionalizing RCM into all acquisitions?
- Study the policies, guidance, and instructions published by the DoD related to ensuring reliability within DoD acquisition programs. Consider a comparative analysis of DoD employed methodologies compared to methodologies employed in commercial industry.
- Compare DoD-wide RCM initiatives to better understand the different levels of success each service has experienced.
- Investigate how receptive major defense contractors would be toward replacing FMEA/FMECA with RCM, to determine if RCM might be mandated in other programs.

APPENDIX. LIST OF ACRONYMS

AAAV	Advanced Amphibious Assault Vehicle
AAV	Amphibious Assault Vehicle
ACAT	Acquisition Strategy
CAIV	Cost as an Independent Variable
CE	Concept Exploration
CPEFH	Cost per Engine Flying Hour
DCACAS	Data Collection and Corrective Action System
DoD	Department of Defense
DoDD	Department of Defense Directive
DRPM-AAA	Direct Reporting Program Manager, Advanced Amphibious Assault
ELAS	Embedded Logistics Administration System
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
GDAMS	General Dynamics Amphibious Systems
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
LMI	Logistics Management Information
MOPP	Mission Oriented Protective Posture
MSG	Maintenance Steering Group
NAVAIR	Naval Air Systems Command
NDIA	National Defense Industrial Association
NPS	Naval Postgraduate School
ORD	Operational Requirements Document
OTH	Over the Horizon
PDRR	Program Definition and Risk Reduction
PM	Program Manager
PMO	Program Management Office
PMO	Planned Maintenance Optimization
RCM	Reliability Centered Maintenance

SAE	Society of Automotive Engineers
SDD	System Development and Demonstration
SECNAVINST	Secretary of the Navy Instruction
SOP	Standard Operating Procedure
SSS	System/Subsystem Specification
USCGC	United States Coast Guard Cutter
USD	Under Secretary of Defense
USMC	United States Marine Corps

LIST OF REFERENCES

1. Hearn, Emmett E., Federal Acquisition and Contract Management. California: Hearn Associates, 1996.

2. Acquisition Reform, "Acquisition Reform: 10 Guiding Principles", [http://depo.dodds-e.odedodea.edu/reform10.htm], May 30, 2001.

3. Defense Systems Management College, Acquisition Logistics Guide, Third Edition, Fort Belvoir: Defense Systems Management College, 1997.

4. Department of Defense Directive 5000.2R, Mandatory Procedures for Major Defense Acquisition Programs and Major Automated Information System Acquisition Programs, June 10, 2001.

5. Department of Defense Directive 5000.1, The Defense Acquisition System, (Incorporating Change 1, January 4, 2001), October 23, 2000.

6. Moubray, John, Reliability-Centered Maintenance II, New York: Industrial Press Incorporated, 1997.

7. SNOINO, "What is Reliability Centered Maintenance?" [http://www.snoino.com/what-is-rcm.htm], February 12, 2002.

8. Dunn, Sandy, "Maintenance Task Selection – Part 3", [http://www.plant-maintenance.com/articles/maintenance_task_selection_part2.shtml], February 12, 2002.

9. SAE [Society of Automotive Engineers] Standard JA1011, Evaluation Criteria for Reliability-centered Maintenance (RCM) Processes, August 1999.

10. SAE Standard JA1012, A Guide to the Reliability-Centered Maintenance (RCM) Standard, January 2002.

11. Clarke, Phil, "The Practical Application of Reliability Centered Maintenance", [http://www.assetpartnership.com/Phil%20Clarke%20ICOMS%202000%20paper.pdf], April 28, 2002.

12. Eaton, Donald R., Logistics Chair, Graduate School of Business and Public Policy, Naval Postgraduate School, Lecture on Reliability, May 16, 2002.

13. Briefing by CWO-5 Jim Gehris, Maintenance Officer, Reliability Centered Maintenance Project Officer, Office of the Direct Reporting Program Manager, Advanced Amphibious Assault Vehicle, on RCM Training, March 25, 2002.

14. Interview between Ms. Nancy Regan, Former RCM Program Manager for NAVAIR (PMA-260b), and Author, August 9, 2002.

15. Chalifoux, Alan and Baird, Joyce, ***Reliability Centered Maintenance (RCM) Guide***, U.S. Army Corps of Engineers Technical Report 99/41, April 1999.

16. Athos, ***RCM, Frequently Asked Question***, [http://www.athoscorp/RCM%20FAQ.htm], July 28, 2002.

17. Naval Air Systems Command, NAVAIR Instruction 4790.20A, Reliability-Centered Maintenance Program, Department of the Navy, Patuxent River, MD, May 1999.

18. Naval Air Systems Command, NAVAIR 00-25-403, Guidelines for the Naval Aviation Reliability-Centered Maintenance Process, Department of the Navy, Patuxent River, MD, February 01, 2001.

19. Naval Sea Systems Command, "CBM and RCM Policy, Process and Procedures", [http://maintenance.navsea.navy.mil/domino/sea04ml/04M1CBM.nsf/cbmHome+?OpenFrameSet], May 26, 2002.

20. U.S. Air Force, "Reliability Centered Maintenance", [https://www.asc.wpafb.af.mil/asc/lp/rcm/], May 25, 2002.

21. U.S. Army Pamphlet 70-3, Army Acquisition Procedures, Department of the Army, Washington D.C., July 15, 1999.

22. U.S. Army Pamphlet 750-40, Guide to Reliability Centered Maintenance for Fielded Equipment, Department of the Army, Washington D.C., May 15, 1982.

23. Reicks Jr., William J., Burt, Richard, Maurana, John P., Steinle, Russell J., “USCGC Healy (WAGB-20) A Case Study for Implementing Reliability-Centered Maintenance”, Marine Technology, Volume 37, No 1, Winter 2000.

24. U.S. Marine Corps Acquisition Procedures Handbook, w/Ch 1, February 16, 2000.

25. SECNAVINST 4105.1 N432, Integrated Logistics Support (ILS) Assessment and Certification Requirements, May 30, 1996.

26. SECNAVINST 5000.2B, Implementation of Mandatory Procedures for Major and Non-Major Defense Acquisition Programs and Major and Non-Major Information Technology Acquisition Programs, December 6, 1996.

27. Direct Reporting Program Manager Advanced Amphibious Assault Vehicle, “AAAV Program Overview” [http://www.aaav.usmc.mil/Prg%20Overview/WebSite_files/frame.htm], January 15, 2002.

28. Interview between CWO-5 Jim Gehris, Maintenance Officer, Reliability Centered Maintenance Project Officer, Office of the Direct Reporting Program Manager, Advanced Amphibious Assault Vehicle, and Author, August 04, 2002.

29. Interview between Mark Delmonico, Director of Logistics, Office of the Direct Reporting Program Manager, Advanced Amphibious Assault, and Author, February 25, 2002.

30. Loren Data Corporation, “Reliability Centered Maintenance for the Marine Corps AAAV”, [http://www.fbodaily.com/cdb/archive/2000/08(August)/15-Aug-2000/Uso1001.htm], May 12, 2002.

31. Interview Between Joel Black, Vice President of Aladon LLC, and Author, July 2002.

32. Gehris, Jim "Promoting Buy-In of the Application of RCM II to a Prototype in a Government/Contractor Acquisition Program” Royal Navy Warship Support Agency, United Kingdom Ministry of Defence, March 13, 2002.

33. Interview Between Colonel Clay Nans, Program Manager, Office of the Direct Reporting Program Manager, Advanced Amphibious Assault Vehicle, and Author, February 25, 2002.

34. Interview Between CWO-5 Jim Gehris, Maintenance Officer, Reliability Centered Maintenance Project Officer, Office of the Direct Reporting Program Manager, Advanced Amphibious Assault Vehicle, and Author, February 25, 2002.

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